

## **Safety and Codes & Standards**

### **Summary of Annual Merit Review Safety and Codes & Standards Subprogram**

#### **Summary of Reviewer Comments on Safety and Codes & Standards Subprogram:**

Reviewers considered hydrogen safety and codes & standards to be critical to the President's Hydrogen Fuel Initiative. The projects were generally deemed to be highly relevant and addressing issues on the critical path to commercialization and the development of a hydrogen economy. Reviewers indicated that projects were well planned, focused and had well understood barriers.

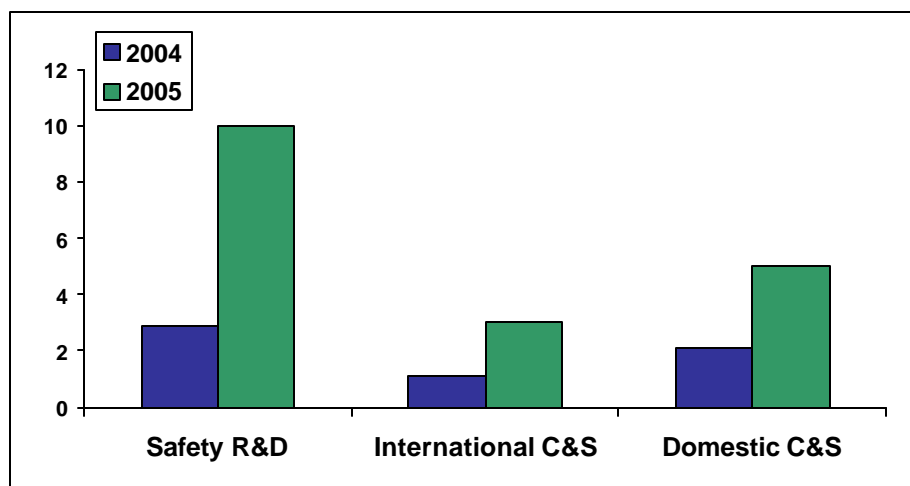
Beyond suggestions for improvement of individual projects, overarching criticism was related to the relatively low level of funding supporting some of the activities.

Additional recommendations and observations by the reviewers included:

- Codes and Standards activities are very long-term in nature. The program needs to keep focused on the long-term.
- There is a general lack of emphasis on safety R&D, instead emphasizing the codes and standards activities. Would like to see clearer definition in the funding that supports each.
- Sensor R&D needs to keep in mind key criteria of cost, durability and stability of output signal.
- Attaining an array of specific sensor performance attributes (operating conditions, linearity, etc.) will be very important in developing useful sensor technology. Also a strong message was delivered that sensor R&D for on-board automotive applications may be misguided and at a minimum should be conducted only as one option for safety engineering, recognizing that the preferred and traditional method for managing fuel safety does not involve reliance upon on-board sensor technology.

#### **Safety and Codes & Standards Funding:**

The funding portfolio for Safety and Codes & Standards addresses Safety R&D as well as both International and Domestic Codes & Standards efforts. The planned 2005 funding profile (subject to congressional appropriation) addresses the National Academies' Report recommendations and provides increased funding in all three of these areas.



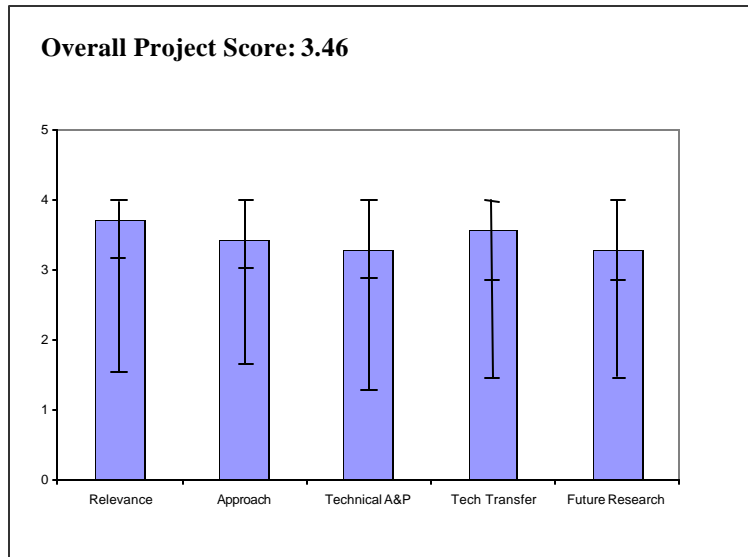
### **Majority of Reviewer Comments and Recommendations:**

In general, the reviewer scores for the safety and codes & standards projects were average to high (the average score for projects being 3.28). Lower scoring projects were related to sensor technology where specific technical deficiencies were cited and where automotive utility is uncertain or doubtful. Major recommendations are summarized below. DOE will act on reviewer recommendations as appropriate for the scope and coherency of the overall safety and codes & standards effort.

- **Codes and Standards development:** Need to remain focused on engaging the right people and organizations. Need to stay focused on the long-term goals.
- **Sensor Technology:** Not clear if all sensor criteria are being addressed as needed (cost, durability, sensor drift, reliability, start-up time, linearity, range, performance or degradation at extreme concentrations). A strong message that on-board sensors have significant shortcomings and are not the preferred method of managing safety on-board vehicles.
- **Safety R&D:** Needs to be expanded, increasing funding. Needs to be broader in scope, and engage appropriate partners.

**Project # SCS-1: Safety and Codes & Standards Subprogram Overview***Davis, Pat; DOE, Team Lead***Brief Summary of Presentation**

The purpose of this Safety, Codes & Standards Subprogram Overview and introduction is to describe subprogram goals/objectives, budgets, barriers/targets, approach to R&D, technical accomplishments, interactions and collaborations, solicitations and awards, and future directions. As such, it sets the stage and puts into context the R&D and analysis projects which will be presented in this subprogram area during the Annual Merit Review.

**Question 1: Relevance to overall DOE objectives**

This presentation earned a score of **3.71** for its relevance to DOE objectives.

- Clearly a top priority to support the Nation's plan.
- Necessary for planning/ building facilities to support H<sub>2</sub> based economic sector.
- Project is very relevant to what is needed in order to establish Safety, C&S.
- There are a number of areas where there are "holes" in this area that need to be filled before hydrogen powered vehicles and power plants are implemented.
- Much needed for continued growth.
- Goals should be tied to project safety performance and safety results.

**Question 2: Approach to performing the research and development**

This presentation was rated **3.43** on its approach.

- Comprehensive- well planned.
- Barriers clearly understood.
- Project is sharply focused on a number technical barriers: 1) adoption of model building codes, 2) identifying the critical gaps, 3) establishing an R&D Roadmap for Hydrogen Safety and identifying key areas where future R&D is needed, 4) develop contact with US and worldwide C&S.
- Global and local participation most important.
- Sharing with the US and international is important.
- Safety priorities should be revised to encourage new research and solicitations.
- Spend less on standard development and "educating" code officials.
- Approach does not seem to address 2nd goal, but addressed somewhat in Key Milestones.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This presentation was rated **3.29** based on accomplishments.

- Key milestones are being met.
- Excellent in light of budget constraints.
- Still too early to properly judge. However, an important milestone has been met regarding identifying key people to assist this effort.
- Progress is being hindered by the "earmarks" which can be clearly seen in the funding profile.
- Budget cuts have slowed progress.
- Safety panel progressing well, but research has been delayed.

#### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This presentation was rated **3.57** for technology transfer and collaboration.

- Without question the effort interfaces with all the C&S efforts underway.
- Has involved industry, C&S officials, universities, as well as research industries.
- Also international involvement.
- Although activity has just begun, the project has had a number of collaborations between International Code Council (ICC) and National Fire Protection Association (NFPA).
- Good involvements.

#### **Question 5: Approach to and relevance of proposed future research**

This presentation was rated **3.29** for proposed future work.

- Well thought out plan.
- There were not enough specifics regarding what the actual research would entail.
- It would be preferable to have future research more clearly defined.
- Long-term goals are reasonable.
- Restoration of budget cuts is critical. Identification of gaps in current C&S also critical.

#### **Strengths and weaknesses**

##### **Strengths**

- Very focused project with clear goals.
- Important and critical area for growth of hydrogen initiatives and economy.
- Safety panel activities.
- The role of DOE in framing (and facilitating) codes and standards is vital to the National effort.

##### **Weaknesses**

- Funds were taken out of the budget in key areas.
- A little more detail regarding actual safety projects would have been beneficial.
- Presentation is very stationary/building oriented.
- Long-term process.
- Very little safety research other than at National Labs and University of Miami.

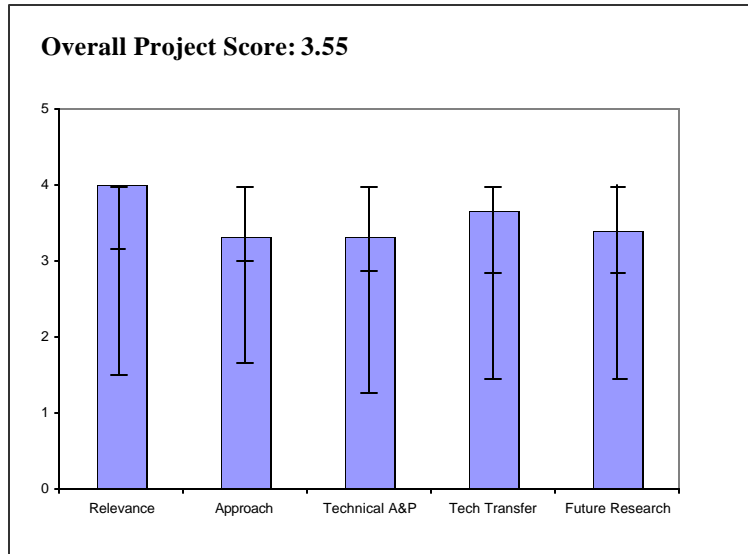
#### **Specific recommendations and additions or deletions to the work scope**

- A more balanced approach regarding the demonstration projects and safety would be recommended.
- Ensure international inclusion.

- Support bonafide safety research and analysis as a high priority rather than using funding for codes and standards, organizations, and code officials training.

**Project # SCS-2: Hydrogen Codes and Standards***Ohi, Jim; National Renewable Energy Laboratory***Brief Summary of Project**

In this project, the National Renewable Energy Laboratory (NREL) will work on hydrogen codes and standards to expedite hydrogen infrastructure development, coordinate such development activities for the Hydrogen Program, and incorporate hydrogen safety considerations into existing and proposed national and international codes and standards. This will be accomplished by bringing together experts to address key issues, coordinating a collaborative National effort between government and industry, and by serving as the central point of contact for up-to-date information on codes and standards activities.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **4.00** for its relevance to DOE objectives.

- Project is an absolute necessity.
- Codes and standards work is critical to the ability to sell, own and operate hydrogen powered vehicles and to install the supporting infrastructures.
- Necessary for coordination of all activities in this area.
- Critical area for continued growth.

**Question 2: Approach to performing the research and development**

This project was rated **3.33** on its approach.

- Well-designed and thought out plan.
- Barriers understood.
- Difficult to evaluate this work along the prescribed criteria since much of the work is in coordination and negotiations among the various code setting bodies and among international organizations.
- Some of the work is reported to be research-based, but there is not enough information about this work to be able to evaluate it.
- Gather international input if available.
- Good practice to incorporate training/continuing education.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.33** based on accomplishments.

- Accomplishments on target.

- There seems to be slow progress; but, again, this may not be unexpected given the nature of much of the work.
- There appears to have been progress with the ICC work and with the establishment of templates, but much of the other work seems to be laying the ground work for future accomplishments.
- Conducting related R&D would be an important part of the effort, but it appears to be a small part and mostly consists of developing roadmaps and one referenced separation distance study.
- Good plan to integrate (template) all areas toward central focus for code adoptions.

#### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.67** for technology transfer and collaboration.

- Collaboration is of the highest degree involving considerable number of organizations.
- Collaborations and interfaces are part and parcel of this task; and are mandatory for success.
- Team appears to be doing a good job.
- Collaboration with all involved parties, including international: 1) not easy, 2) necessary, 3) good work/organization.
- Positive intent to combined approach with multiple stakeholders.

#### **Question 5: Approach to and relevance of proposed future research**

This project was rated **3.40** for proposed future work.

- Well planned outline for needed work to effectively reduce barriers.
- Expect promising outcome in the future especially in technical support for developing new hydrogen standards.
- Timetable/ not sure that crash testing will be done in 2007.
- C&S time table: push R&D and delay C&S setting until data is available.
- Need to discuss FY 05 draft standard for H<sub>2</sub> sensors/detectors.

#### **Strengths and weaknesses**

##### Strengths

- A vital part of the overall National hydrogen effort.
- Important area for future growth.

##### Weaknesses

- Remember to focus on getting right people, not just right industry sectors for workshops.
- Development will be "long-term."

#### **Specific recommendations and additions or deletions to the work scope**

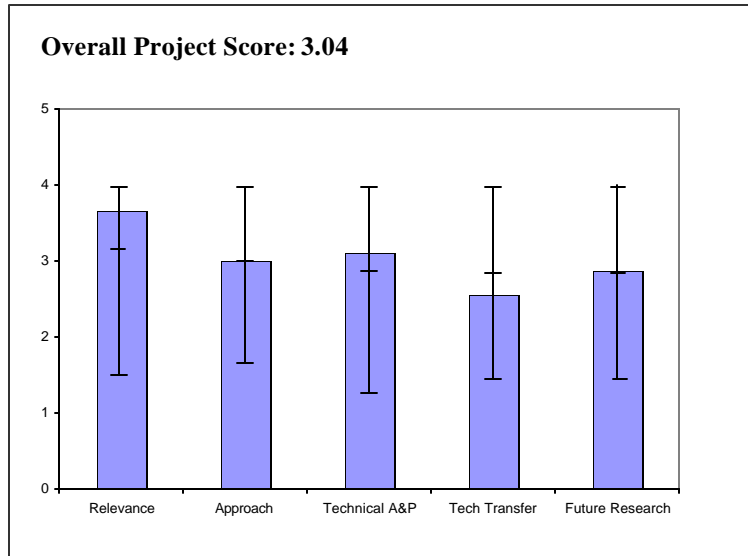
- Would like to see clear definition between portion of budget that is directed towards interfaces with code setting bodies, international agencies, etc. and that part of the budget that is used specifically for R&D.

**Project # SCS-3: Electrochemical Sensors for PEMFC Vehicles***Martin, Jim; Lawrence Livermore National Laboratory***Brief Summary of Project**

Lawrence Livermore National Laboratory (LLNL) is developing solid-state electrochemical sensors for safety and fuel monitoring applications. The safety sensor will utilize new electrode materials and well-known oxygen conducting ceramics. The fuel sensor will utilize novel proton conducting ceramics in a traditional sensor concept.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.67** for its relevance to DOE objectives.



- Safety/fuel sensor work of utmost importance.
- Work on hydrogen sensors clearly supports the Hydrogen Fuel Initiative because the technology needs to be developed to support potential applications.
- While the research is important if sensors are needed, it is also relevant to note that support for the research should not be interpreted as agreement among the auto companies that sensors are required.
- Sensor technology needs to be developed in case it is needed for application in automotive use.
- Relevance to DOE overall objectives not well described.
- H<sub>2</sub> sensor technology is not yet perfected, and this work is very valuable.
- Key part of program.

**Question 2: Approach to performing the research and development**

This project was rated **3.00** on its approach.

- The many barriers and technical problems are identified.
- Good that PI is keeping in mind an awareness of the need for eventual commercialization of this technology.
- Clearly lower operating temperatures and operating voltages are needed in order for the sensor to be commercially practical.
- Need to establish whether this can be done in the commercialization phase or if additional research is needed.
- Natural gas is not typically found in a garage.
- Fuel sensor work is good.
- Safety sensor work: OEMs will engineer consumer-phase vehicles that don't require H<sub>2</sub> leak sensors.
- Good approach which evaluates different sensor technologies.
- Application could be broader and/or redirected.



### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.11** based on accomplishments.

- Considerable lab work done.
- Good progress.
- Need to evaluate sensor drift. Need to quantify sensor start-up time with response time. High temperature sensors generally take longer for start-up time than lower temperature sensors.
- Fuel sensor technology will be very valuable in the future to measure in-line H<sub>2</sub> quality.
- Lots of good data with one test configuration.

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **2.56** for technology transfer and collaboration.

- Interaction with other institutions seems lacking except for 'discussion' with others (Auto, FC, etc.).
- Mentions papers written and presentations made as well as discussion with one fuel cell manufacturer and two auto makers.
- Collaborations not specifically described.
- Confirm/consider collaboration with industry and other sensor developments.
- Though a challenge, need to develop relations with partners/users; otherwise technology is guaranteed to sit unused on the shelf.
- Collaboration with potential manufacturer currently absent.

### **Question 5: Approach to and relevance of proposed future research**

This project was rated **2.88** for proposed future work.

- Proposed work is a fabrication method.
- Timeline/ milestones do show other efforts but not discussed.
- Not assessed as it appears the project is ending.
- Future research not described in much detail.
- Confirm sensors will operate in low (-50F) temperature external environments. As shown, the sensor requires about 440C for operation which may not be practical.
- Sensitivity to hydrocarbon typically formed in a garage, e.g. gasoline, diesel, paint thinner, etc., needs to be confirmed or included in the program. Natural gas not typically formed.
- Confirm operating temperatures of 440C will not present an ignition source for a large H<sub>2</sub> release.
- Confirming sensor life is a function of time and not a function of mass of H<sub>2</sub> absorbed. For example, a large release of say 1-2 parts of H<sub>2</sub> does not consume the sensor life.
- If on-board fuel processing decision is no-go, verify need for H<sub>2</sub> sensors.
- Some fundamental questions still need to be explored in order to stimulate interest in commercialization.

### **Strengths and weaknesses**

#### **Strengths**

- Excellent work.
- Methodical plan of work.
- A comprehensive investigation of sensor technologies available and future possibilities.

- Good sensitivity, linear response.

#### Weaknesses

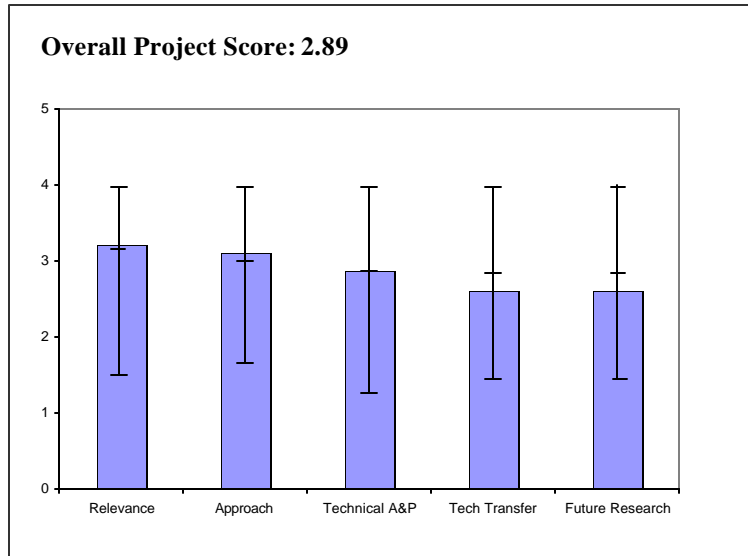
- Cost and durability?
- Investigation of sensor drift.
- The need to heat electrode will inherently raise reliability questions and start-up time questions.

#### **Specific recommendations and additions or deletions to the work scope**

- Reiterate that sensor research is valuable in case individual auto makers determine that sensors are needed in their products, but care needs to be exercised not to imply that, while the R&D is valued, on-board sensors ought to be maintained.
- Consider the issue that for many of the separation technologies and many of the off-gasses produced , e.g. CO/CO<sub>2</sub>/O<sub>2</sub>, may present additional hazards.
- Future work may need to confirm cost effective availability and application reliability of these other sensors under required environmental exposures.
- If funding/timing is available, fuel sensor development is a valuable effort to pursue further for in-line hydrogen quality sensing.
- Use different test set up that introduces cold H<sub>2</sub>-air mixtures to heated electrodes.
- Explore signal response reduction at H<sub>2</sub> concentration >4%. Explanation of O<sub>2</sub> limitation is not convincing.

**Project # SCS-P1: Interfacial Stability of Thin Film H<sub>2</sub> Sensors***Pitts, Roland; National Renewable Energy Laboratory***Brief Summary of Project**

The National Renewable Energy Laboratory (NREL) is currently working to develop and make technology available that would produce safe, reliable, sensitive, fast, lightweight, and inexpensive hydrogen sensors. To do this, NREL will look at the factors affecting the stability and performance of thin film sensors, such as suspect contaminant gases, temperature variations, and humidity impacts, in practical environments and find solutions for extending the lifetime and functionality of thin film hydrogen sensors.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.22** for its relevance to DOE objectives.

- H<sub>2</sub> sensor work critical to program.
- Work on the hydrogen sensors clearly supports the Hydrogen Fuel Initiative because the technology needs to be developed to support potential applications.
- While the research is important if sensors are needed, it is also relevant to note that support for the research should not be interpreted as agreement among the auto companies that sensors are required.
- Sensor technology needs to be developed in case it is needed for application in automotive use.
- Difficult to understand relationship to overall DOE objectives.
- This project is very relevant, but falls short on a few goals such as lifetime and response time.
- Having reliable, inexpensive sensors is a critical need. However, there may be other approaches and sensor concepts to accomplish that need.

**Question 2: Approach to performing the research and development**

This project was rated **3.12** on its approach.

- Barriers properly identified, approach to solutions clear and straight forward.
- Approach seems sound, but it appears that the project has taken a rather long time to get to its present status.
- Approach appears to be well designed.
- More work could be done regarding integration in other research.
- Safety fully addressed.
- Difficulty in establishing lower temperature limit.
- Concept is ideally suited for use with distributed fiber optic based signals and control systems.

### **Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **2.88** based on accomplishments.

- Effectiveness, etc. -- good progress.
- Cost needs to be addressed.
- PI seems to have a reasonable approach to sensors, but will need to assess whether the design can be affordably manufactured if intended for automotive applications.
- PI indicated that he is looking at stationary applications which may be more appropriate for the level of sophistication in the design.
- Good progress.
- This project started in 1994 - 10 years ago! I don't think much progress has been made relative to the time invested.
- The project has come close to meeting DOE goals; however, research has been ongoing for years and durability improvements, improvements in temperature range, and accuracy were not described.
- Slow process to objectives.
- Excellent sensitivity.
- Fast response.
- Need to find film materials that will not saturate at concentrations  $<10\%$   $H_2$ .

### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **2.62** for technology transfer and collaboration.

- For the work scope the participants are appropriate.
- Need pipeline collaborators to ensure applications of technology.
- Some collaboration were shown.
- Need private industry collaboration to accelerate production development and commercialization.

### **Question 5: Approach to and relevance of proposed future research**

This project was rated **2.62** for proposed future work.

- Well identified but no timeline.
- No reference in poster material to future plans; perhaps because research appears to be nearing its end.
- Need to get on with getting this project finished.
- Confirm/consider future work will include exposure to heavier chain hydrocarbons e.g., gasoline, diesel, paint thinner, etc. that might typically be found in a garage environment.
- Vehicles will be engineered to handle  $H_2$  safely without leaks, or they won't happen.
- A more disciplined approach to meeting DOE goals (and/or surpassing) should be a part of the presentation.
- There is no clear end in sight.
- Good foundation to future commercialization.

### **Strengths and weaknesses**

#### **Strengths**

- Innovative sensor technology.

- Many of the DOE goals met.
- Enthusiastic ownership.
- Conceptual design.
- Sensitivity.

#### Weaknesses

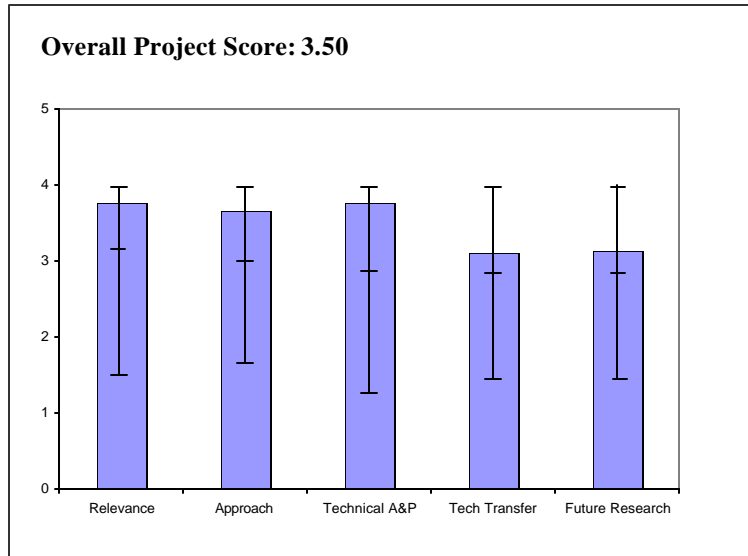
- The OEMs do not intend to engineer FC vehicles that will require H<sub>2</sub> sensors- no more so than do gasoline vehicles today. So focus on vehicle application is misguided.
- Timeframes needs to be more goal oriented for future work.
- Limit of range or linearity.
- Film saturation at relatively low H<sub>2</sub> concentrations.
- Sensor work seriously behind the power curve.

#### Specific recommendations and additions or deletions to the work scope

- Scope needs to be expanded to field-validate in real applications.
- Need to take the next step and include "array" concepts, total system awareness, feedback systems, etc.
- Reiterate that sensor research is valuable in case individual auto makers determine that sensors are needed in their products, but care needs to be exercised not to imply that, while the R&D is valued, on-board sensors ought to be maintained.
- Consider that for many of the separation technologies and many of the off-gasses produced, e.g. CO/CO<sub>2</sub>/O<sub>2</sub> may present additional hazards.
- Future work may need to confirm cost effective availability and application reliability of the other sensors under required environmental exposures.
- Add focus on pipeline application.
- Indication of actual status for goals not yet met would be more helpful to judge the project.
- DOE targets need to have a target date.
- Explore feasibility of both a simpler, inexpensive onboard sensor for vehicle use, and another more elaborate design to provide H<sub>2</sub> concentrations for use in facility DCS intelligent signal processing.

**Project # SCS-P2: Codes & Standards Analysis***Swain, Michael; University of Miami***Brief Summary of Project**

The University of Miami is working on codes and standards to conduct a building safety analysis for the California Fuel Cell Partnership (CaFCP), including an assessment of safety issues related to garaged vehicles. They will develop a method to determine hydrogen sensor placement, and analyze safety issues for the writing of codes and standards. This will be accomplished by identifying concerns on hydrogen installations and designing, testing and verifying computer programs to accurately model hydrogen interactions.

**Question 1: Relevance to overall DOE objectives**

This project earned a score of **3.78** for its relevance to DOE objectives.

- The characterization of H<sub>2</sub> behavior, true ignition parameters and related aspects are crucial to the program.
- Data regarding hydrogen flammability will be key in the establishment of codes and standards.
- This study continues work done in the areas of hydrogen flammability characteristics.
- Title is misleading -- should be something about flammability limits.
- Excellent work needed at this time period to make realistic judgment calls on C&S relating to setback distances.
- Good foundation to an issue of concern for future commercialization.
- Good general objective, but not focused on any specific standard or application.

**Question 2: Approach to performing the research and development**

This project was rated **3.67** on its approach.

- The approach it is well understood.
- The PI uses a combination of sophisticated analytical and prediction tools and rather simple experimental methods to illustrate hydrogen flammability limits.
- The simple illustrative methodologies appear to be useful in demonstrating hydrogen properties to the code setting activities and to government and public bodies.
- Work was methodical and conclusive, and the results were clear.

**Question 3: Technical accomplishments and progress toward project and DOE goals**

This project was rated **3.78** based on accomplishments.

- Accomplishments continue to be unprecedented.

- PI continues to develop data and illustrative information to support codes and standards.
- The project achieved its goals and targets.
- This work changes the historical assumptions on real world ignition energy of H<sub>2</sub> LFL conditions.
- The ignition sources that were evaluated were actual household appliances.
- Interesting test data, but no plan on how to use data or generalize it.

#### **Question 4: Technology transfer/collaborations with industry, universities and other laboratories**

This project was rated **3.11** for technology transfer and collaboration.

- Project very unique, so interaction would be limited.
- None listed or mentioned.
- Consider even more interactions and education with fire marshals.
- Transfer of information will or has been given to the key C&S organizations which deal with setback distances.
- No collaboration besides SNL.

#### **Question 5: Approach to and relevance of proposed future research**

This project was rated **3.14** for proposed future work.

- Future work limited to reporting progress.
- No specific plans were noteworthy, but a continuation of current research would be valuable.
- Not applicable.
- Should move next to model more realistic release scenarios (smaller holes, higher P).
- The future work detailed was only regarding an upcoming presentation.
- Future work does not address other areas where real world LFL studies would be beneficial.
- Project appears complete.
- No plans on next step.
- No future research identified by PI.
- This work is most valuable to the overall effort.

#### **Strengths and weaknesses**

##### **Strengths**

- The work is laying out the groundwork to challenge the NFPA 70 (NEC) Group B class for H<sub>2</sub> (something done decades ago) in my opinion, which needs to be done.
- Good work and relevant.
- Good practical testing of light switches, garage door openers etc. – this is an important education piece.
- Clearly documented, disciplined work which will assist in making setback distances based on material properties and not undue fears of H<sub>2</sub>.
- Good video clips of flame blow off under some conditions, and flashback to release site under other conditions.

##### **Weaknesses**

- The funding level of this activity is much too low.
- Underwriter's Lab and others need to be part of this project.
- No plan to generalize data or apply it to other ignition sources and scenarios.

- No review of similar tests performed previously.

**Specific recommendations and additions or deletions to the work scope**

- Expand scope -- the criticality of imposing NFPA70 as non written on small H<sub>2</sub> systems will be a significant cost burden to implementing the "H<sub>2</sub> economy" and NFPA "group B" is technically flawed and has been for decades.
- The C&S title is too general as the scope was to evaluate LFL relating to setback distances.
- Should be maintained.
- Confirm (resources are provided) / consider (providing research) for integration of this work with LLNL/SNL/SRI's work on release rates, heat flux, etc. as well as risk (frequency of a release with associated consequences) to aid NFPA/ICC in determining appropriate cost effective, risk based, setback distances.
- Future work needs to be concentrated not just in setback distances, but a suggestion would be enclosed facility LFL studies in order to realistically evaluate alarm levels/need for H<sub>2</sub> alarms and sensors in facilities which store H<sub>2</sub> vehicles, etc.
- Solicit input from technology validation projects on relevant ignition scenarios.